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A. Naghizadeh · A. H. Mahvi · A. R. Mesdaghinia · M. Alimohammadi

Application of MBR Technology in Municipal Wastewater Treatment

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Abstract The membrane bioreactor (MBR) is one application of membrane technology in wastewater treatment. Submerged MBRs, in which membranes are directly submerged in the aeration tank, have received significant attention because of their several advantages, including improved and more reliable effluent quality. In this study, the performance of hollow fiber micro filtration membranes immersed in a bioreactor for removal of chemical oxygen demand (COD), total suspended solids (TSS) and turbidity from municipal wastewater containing industrial wastewater was studied at different hydraulic retention times. The results demonstrate high treatment efficiencies for COD, TSS and turbidity, and the concentrations of these pollutants under all operating conditions were reduced to as low as 9 mg/L, 1 mg/L and 0.3 NTU, respectively. Therefore, this technology may be regarded as a promising treatment method for various applications in wastewater effluent reuse.

Keywords MBR · COD · TSS · Turbidity · Municipal wastewater · Reuse

الخلاصة

إن المفاعلات الحيوية ذات الأغشية هي واحدة من تطبيقات تكنولوجيا الأغشية لمعالجة مياه الصرف الصحي "غشاء المفاعل الحيوي المغمور" ، حيث إن الأغشية التي تغمر مباشرة في خزان الهواء تلقى المزيد من الاهتمام بسبب العديد من المزايا مثل نوعية النفايات السائلة الأفضل والأكثر موثوقية .

وفي هذه الدراسة تم الحصول على النتائج باستعمال ألياف أغشية الترشيح الدقيقة المجوّفة المغمورة في المفاعل الحيوي ، وتطبيقها في كمية الأكسجين الكيميائي المطلوبة COD ومجموع المواد الصلبة العالقة TSS وإزالة العكر من مياه الصرف الصحي البلدية التي تحتوي على بعض كميات مياه الصرف الصناعية والتي درست على أوقات حجز هيدروليكية مختلفة .

وقد أظهرت النتائج كفاءة عالية في معالجة كمية الأكسجين الكيميائي المطلوبة COD و مجموع المواد الصلبة العالقة TSS والعكر، وانخفضت تراكيز هذه الملوثات في جميع الظروف التشغيلية لتصل لانخفاضات حتى 9 مغم/لتر, 1 مغم/لتر و 0.3 NTU على التوالي.

ويمكن – بناء على ذلك - عدُّ هذه التكنولوجيا تبشيرا لمرحلة علاج واعدة لتطبيقات مختلفة من إعادة استخدام المياه العادمة المتدفقة .

A. Naghizadeh · A. H. Mahvi (✉) · A. R. Mesdaghinia · M. Alimohammadi
School of Public Health and Center for Environmental Research,
Tehran University of Medical Sciences, Tehran, Iran
E-mail: ahmahvi@yahoo.com

A. H. Mahvi
National Institute of Health Research, Ministry of Health, Tehran, Iran

1 Introduction

In the last few years, the wide exploitation of limited water resources and the need to preserve high quality water for potable uses has resulted in increased interest in the reuse of treated wastewater [1]. Discharge of domestic and industrial wastewater to surface and groundwater resources is very damaging to the environment [2]. Solid–liquid separation during biological wastewater treatment is difficult so membrane bioreactors (MBRs) have been one of the most widely used solutions since the late 1960s [3]. MBR technology and its application in domestic and industrial wastewater treatment systems has recently attracted closer attention because of demands to deliver effluents of higher standards and with more reliable quality. Such applications can be broadly defined as systems integrating biological degradation of wastewater with membrane filtration. They have proven to be effective in removing organic and inorganic contaminants as well as biological entities [4,5]. MBRs combine suspended growth activated sludge biological treatment and membrane filtration to perform the critical solids/liquid separation function that is traditionally accomplished using secondary clarifiers. Traditional treatment systems use an aeration tank, secondary clarification, and possibly tertiary filters. In MBRs, the secondary clarifier is replaced by a membrane filtration unit [6,7] employing ultrafiltration or microfiltration membranes for the complete retention of sludge; this leads to an increased microbial concentration within the reactor [8].

Over the past decade, membrane technologies have revolutionized water and wastewater treatment. In water, wastewater, recycled water, and industrial treatment applications, microfiltration and ultrafiltration membranes are used to separate solids from the fluid by physical straining. The main advantages of MBRs may be summarized as (1) producing exceptional effluent quality, (2) possessing a small footprint, thus making them attractive where space is limited and where water treatment for internal recycling is desirable, e.g. for buildings (with equipment generally located in a cellar) or on ships, (3) having modularity, (4) having a robust and reliable operation, and (5) reducing downstream disinfection requirements [9]. MBRs have thus received increasing attention in recent years for their advantages in wastewater treatment [10].

There are two general types of membrane systems that can be used in MBRs: pressure-driven, in-pipe cartridge systems that are located external to the bioreactor and vacuum-driven, and immersed systems that are designed for installation within the bioreactor [11]. MBR technology is as suitable for the treatment of domestic wastewater as it is for industrial wastewater [12,13]. The organic loading rate (OLR) has a significant relationship with feed concentration and hydraulic retention time (HRT). In general, a short HRT can induce a large OLR. Thus, HRT is expected to be an important operating parameter in MBR systems, correlated not only to the treatment efficiency of the MBR system itself [14,15] but also to the characteristics of the biomass in the activated sludge system [16,17].

In this study, we investigated the application of a pilot scale MBR operating at different HRTs during the cold season for organic matter removal based on chemical oxygen demand (COD), total suspended solids (TSS) and turbidity removal in domestic wastewater. The performance of the MBR was determined with a fixed sludge retention time (SRT = 20 days) and pH value (6.8–7.1) over various HRTs (4, 6, 8, 10 and 12 h).

2 Material and Methods

This study was performed in a municipal wastewater treatment plant in which a pilot scale MBR system was fed from a municipal wastewater canal following fine screening. A small number of industries, for example a battery manufacturer, discharge their effluent to this municipal wastewater. The system consisted of a completely mixed aeration tank in which a bundle of hollow fiber membranes was submerged. The aeration tank was $60 \times 25 \times 50$ cm, with an effective volume of 48 L. The membrane was made of polypropylene, with a pore size of 0.1 μm and a filtration area of 4.0 m^2 (Zenon Co., Canada). To initiate the MBR, the bioreactor was filled with recycled activated sludge from a wastewater treatment plant and then, to raise the mixed liquor suspended solids (MLSS) concentration to 13–14 g/L, the activated sludge was fed with nutrient materials (glucose, $(NH_4)_2SO_4$, KH_2PO_4, $MgSO_4$, $NaHCO_3$, $FeCl_3$, $MnSO_4$ and $CaCl_3$). Raw wastewater was supplied from the inlet channel to the aeration tank by a diaphragm pump (Jescko Model, Pulsafeeder). An air diffuser beneath the membrane module was used for aeration and mixing of the liquor. The membrane-filtered effluent was continuously removed with a suction pump (Procon Model) connected to the membrane module. The MBR was operated in on/off cycles of 10 and 4 min, respectively. A level sensor was applied to maintain a fixed water level in the reactor by controlling the power to the influent pump. A series of hydraulic retention times (HRT = 12, 10, 8, 6 and 4 h) were examined by adjusting the rotation speed of the feed and suction pumps to maintain a constant filtration flux. The operating conditions are summarized in Table 1. The system

Table 1 Operating conditions of the pilot scale MBR

Items	Runs (h)				
	HRT = 12	HRT = 10	HRT = 8	HRT = 6	HRT = 4
Q (L/h)	4	4.8	6	8	12
Flux (L/m^2 h)	1	1.2	1.5	2	3
SRT (d)	20	20	20	20	20
pH	7.11	7.12	7.2	7.17	7.25
DO (mg/L)	3	2.94	3.07	2.99	3.02
MLSS (g/L)	13–15	13–15	13–15	13–15	13–15

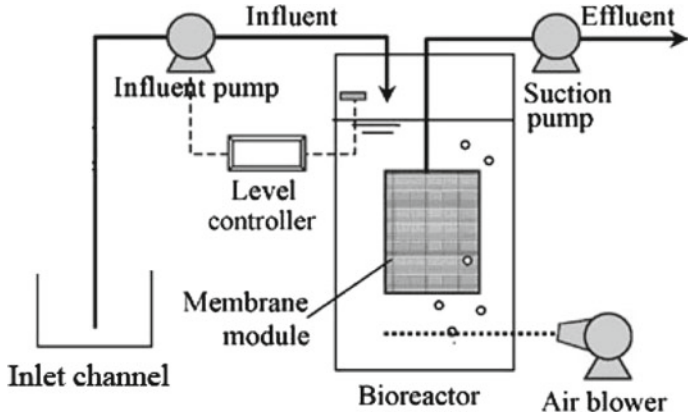

Fig. 1 Schematic of the submerged membrane bioreactor pilot

was tested for eight days after reaching steady state during each run. To determine steady state, the COD of the effluent stream was measured daily and plotted against time. When this curve reached a constant level, the system was judged to be at steady state. COD, TSS and turbidity concentrations in both influent and effluent were measured daily during each run and the average values calculated as the arithmetic mean of the data collected at the different sampling periods.

The levels of influent and effluent COD at different hydraulic retention times were determined according to standard methods (method 5220C). TSS was analyzed gravimetrically following standard methods [18]. Finally, turbidity was measured with a turbidity meter under all operating conditions (Fig. 1).

3 Results and Discussion

The results presented in this study were all obtained at the pilot scale operating under steady state conditions, mainly below 10°C. Results clearly show that the submerged MBR could successfully reduce the COD, TSS and turbidity of municipal wastewater.

3.1 COD Removal

The MBR system removed COD at a high rate under all operating conditions, despite the fact that various levels of industrial wastewater had been discharged into the municipal wastewater. The mean COD removal efficiencies under all operating conditions are summarized in Fig. 2 and Table 2.

The MBR effluent COD was <9.2 mg/L under all operating conditions. As shown in Fig. 2, despite fluctuations in the influent COD, the amount of COD in the effluent flow was relatively constant and COD removal under all operating conditions was greater than about 96%. This result is in accordance with Shin et al. [19], who investigated the performance of a pilot-scale submerged MBR coupled with a sequencing batch reactor and reported COD removal values higher than 95%, despite large fluctuations in influent conditions. The total COD removal efficiency in the bioreactor was maintained above 96%, regardless of HRT conditions. It can be seen from Fig. 2 and Table 2 that the membrane contributed significantly to COD removal due to the complete retention of all particulate and macromolecular COD compounds by the membrane. The lower removal

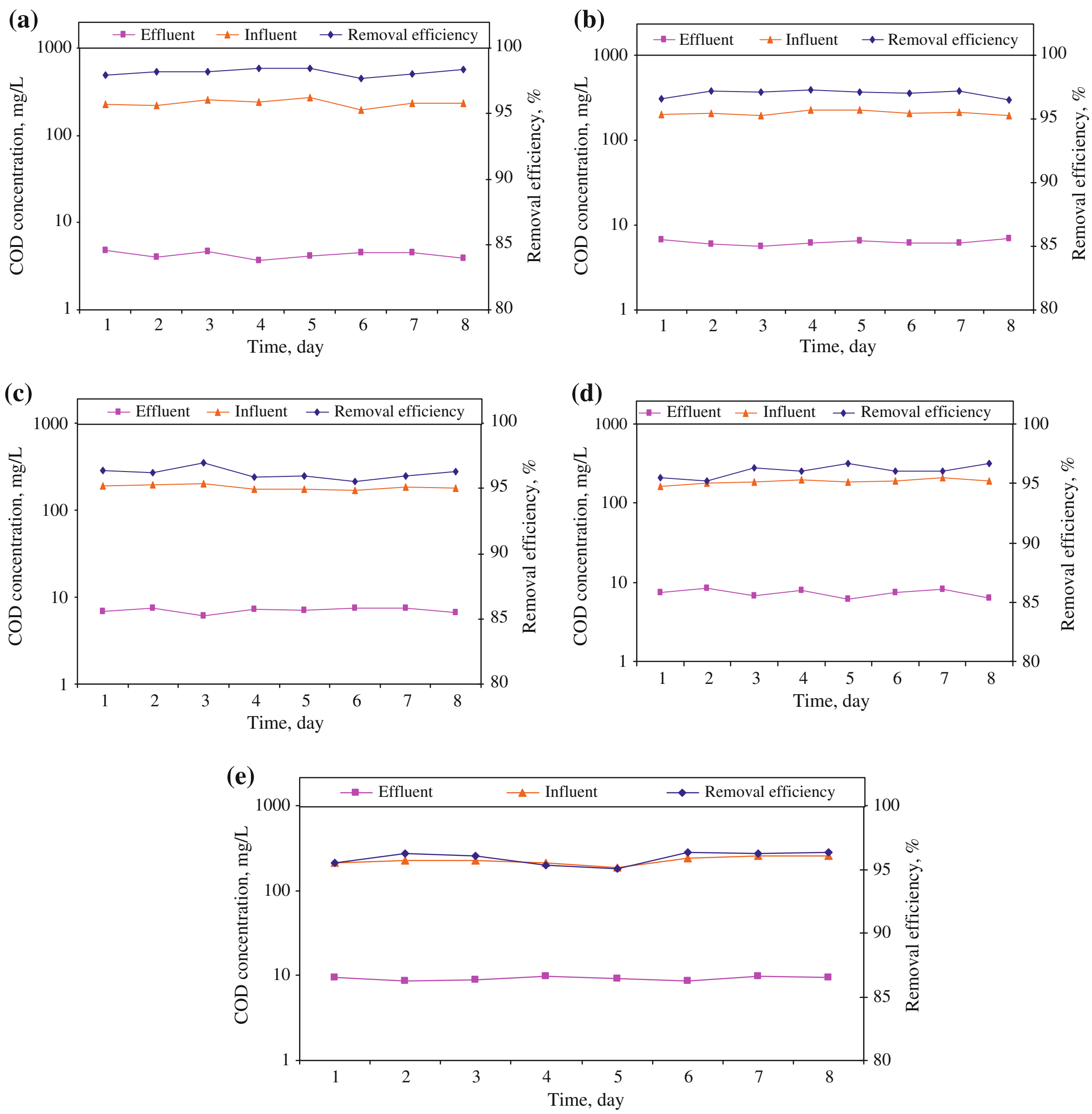

Fig. 2 COD removal rates. **a** HRT = 12, **b** HRT = 10, **c** HRT = 8, **d** HRT = 6, **e** HRT = 4 h

Table 2 COD removal efficiency under different operating conditions

	Runs (h)				
	HRT = 12	HRT = 10	HRT = 8	HRT = 6	HRT = 4
Influent (mg/L)	235.25	210	183.13	187.87	226.12
Effluent (mg/L)	4.3	6.28	7.037	7.37	9.21
Removal (%)	98.172	97	96.15	96.07	95.93

efficiency at short hydraulic retention times might be due to the existence of non-biodegradable materials in municipal wastewater that originated from the discharge from industrial sources. Therefore, to attain higher COD removal efficiency, it is necessary to operate at higher hydraulic retention times in accordance with Stephenson et al. [20] and Gao et al. [21], who reported that HRT values of 10.5–389 h were required for industrial wastewater treatment. One possible cause of the lower COD removal efficiency at short HRTs may be the low temperatures during the pilot operation period, because this investigation was performed during autumn and winter, when the temperature was below 10°C. It is well known that the best temperature for activation and survival of (mesophilic) activated sludge microorganisms is about 25–35°C, so the low COD removal efficiency observed at short HRTs may have been primarily to the result of deactivation of microorganisms at low temperature. These results are in agreement with Kraume et al. [22], who reported that in comparison to the conventional activated sludge process, which typically achieves 95% COD removal, the efficiency can be increased to 96–99% in MBRs. Their study also indicated that the MBR system can provide a consistently high COD removal efficiency even under difficult operating conditions.

From Table 3, it can be seen that the permeate COD concentration was much lower than the maximum accepted standards for discharge to surface water, injection wells and for agricultural uses in Iran. This effluent can be directly fed to an RO system and the treated water could be recycled and reused for cooling tower make-up water or other purposes.

Table 3 COD and TSS effluent standards in Iran

Different discharges	Items (mg/L)	
	TSS	COD
Discharge to surface water	40	60
Discharge to injection well discharge	–	60
Discharge to agricultural uses	60	200

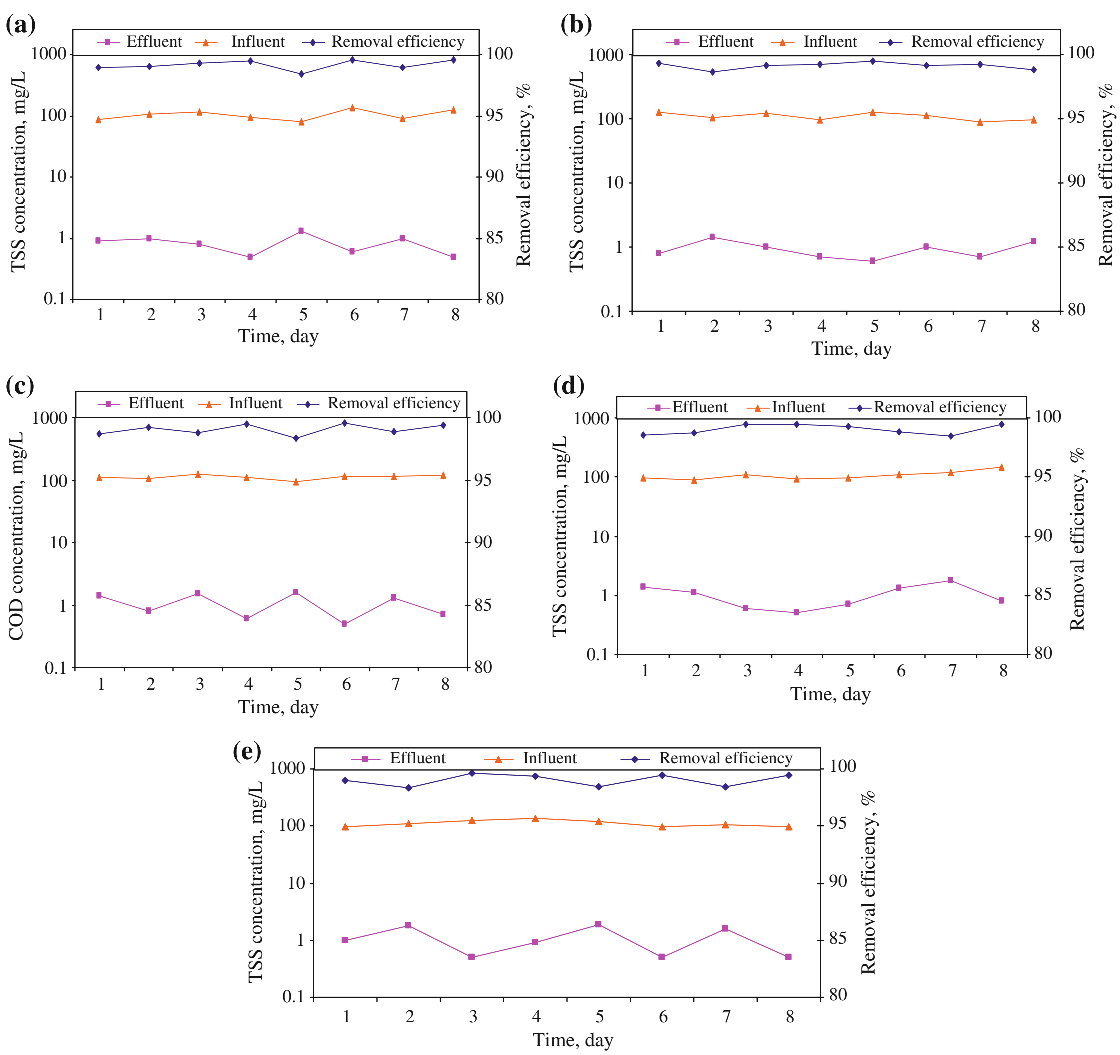

Fig. 3 TSS removal rate. **a** HRT = 12, **b** HRT = 10, **c** HRT = 8, **d** HRT = 6, **e** HRT = 4 h

3.2 TSS Removal

It can be seen from Fig. 3 and Table 4 that the effluent TSS levels were low, probably because a microfiltration membrane was used. The TSS removal efficiency under all operating conditions was >99%. Moreover, the effluent TSS levels did not exceed 1.1 mg/L.

Table 4 TSS removal efficiency under different operating conditions

	Runs (h)				
	HRT = 12	HRT = 10	HRT = 8	HRT = 6	HRT = 4
Influent (mg/L)	104.4	109.4	112.1	107.6	110.5
Effluent (mg/L)	0.8	1	1.05	1.02	1.1
Removal (%)	99.2	99.08	99.06	99.04	99.01

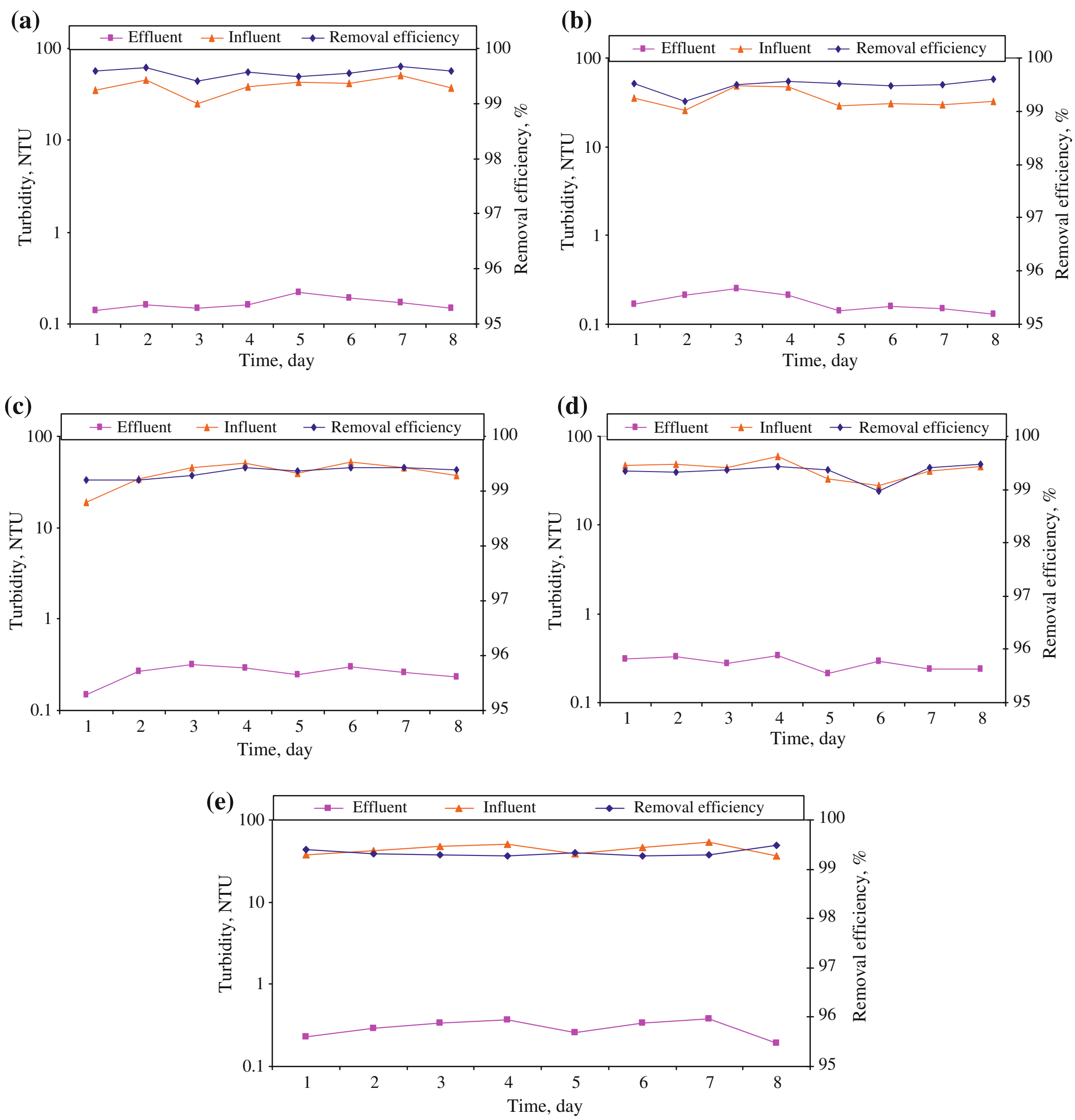

Fig. 4 Turbidity removal rates. **a** HRT = 12, **b** HRT = 10, **c** HRT = 8, **d** HRT = 6, **e** HRT = 4 h

Table 5 Turbidity removal efficiency under different operating conditions

	Runs (h)				
	HRT = 12	HRT = 10	HRT = 8	HRT = 6	HRT = 4
Influent (NTU)	39.5	34.8	40.4	43.5	44.2
Effluent (NTU)	0.16	0.17	0.25	0.28	0.3
Removal (%)	99.6	99.5	99.4	99.3	99.3

These results are in good agreement with previously published reports such as that of Harper et al. [23]. They compared an MBR system with a SBR system and reported that the MBR effluent TSS was <2 mg/L under all operating conditions, compared with an SBR effluent TSS that ranged from 8 to 21 mg/L. This effluent TSS concentration was also much lower than the level of TSS in other conventional wastewater treatment processes. The results of Fig. 3 and Table 4 clearly indicate that the MBR system produced an effluent stream with excellent quality. Because this low level of TSS in the effluent should consume a lower amount of disinfectant, the overall cost of treatment would not be expected to be high.

3.3 Turbidity Removal

Turbidity levels of influent and effluent samples were measured over the operating periods and results are presented in Fig. 4 and Table 5. As shown, the average amounts of turbidity under all operating conditions were below 0.3 NTU. In other words, the efficiency of turbidity removal under all operating conditions was >99.3%.

These results are in agreement with results reported by Adham et al. [24], who compared various MBRs manufactured by different companies and concluded that the Zenon MBR effluent on-line turbidity performance did not exceed 0.5 NTU at any time and also reported that turbidity of effluent under all operating conditions was close to the accepted standard for potable water. Consequently, the MBR system has a high ability to remove organic matter, TSS and turbidity and the MBR effluent can be sent directly to RO for demineralization.

4 Conclusions

In this project, the application of a submerged MBR operating at different hydraulic retention times for municipal wastewater treatment and reuse was investigated. A satisfactory effluent quality was obtained at all HRTs and the COD removal efficiencies under all operating conditions were >96%. COD removal in the bioreactor decreased slightly with decreasing HRT. The TSS removal efficiencies under all operating conditions were >99% and thus the TSS concentration of the effluent was consistently below 1.1 mg/L. Turbidity removal efficiencies for all parts of the experiments were >99.3%, and this high treatment efficiency produced effluents with turbidities below 0.3 NTU. Thus, it can be concluded that MBR technology produces excellent quality permeate, suitable for various water reuse applications. Immersed membrane technology has a number of significant benefits for the treatment of municipal wastewater over many currently utilized treatment processes such as conventional activated sludge systems and sand filtration, even at very low temperatures. The high-quality effluent produced by a MBR can either be used directly for water reuse applications after disinfection or be fed directly into a reverse osmosis process without further pretreatment.

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